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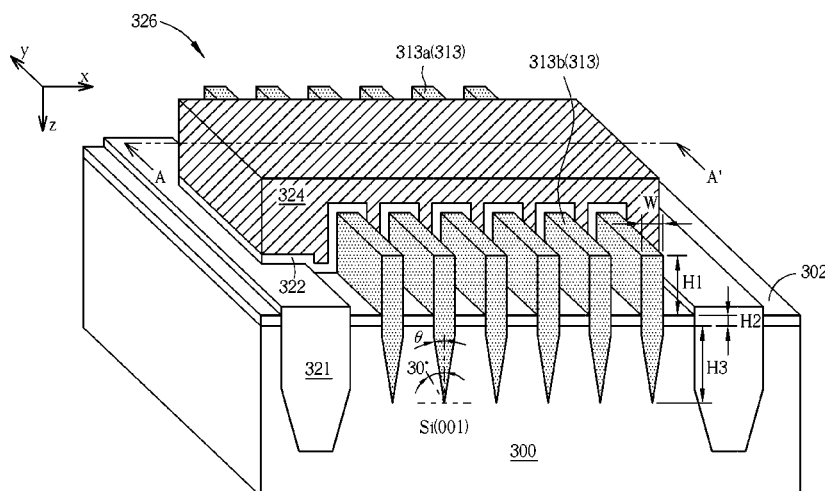
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- (57) **ABSTRACT**

- USPC 438/481
See application file for complete search history.



14 Claims, 7 Drawing Sheets

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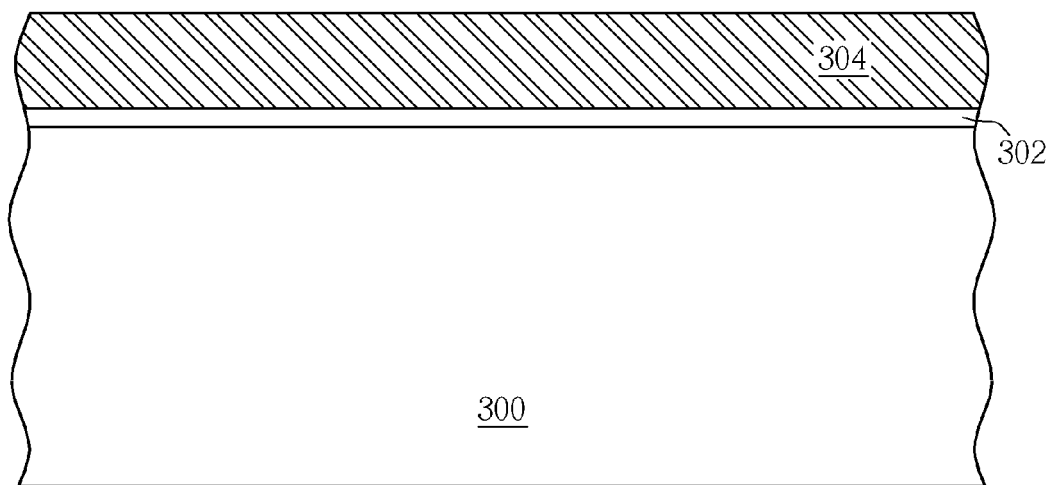


FIG. 1

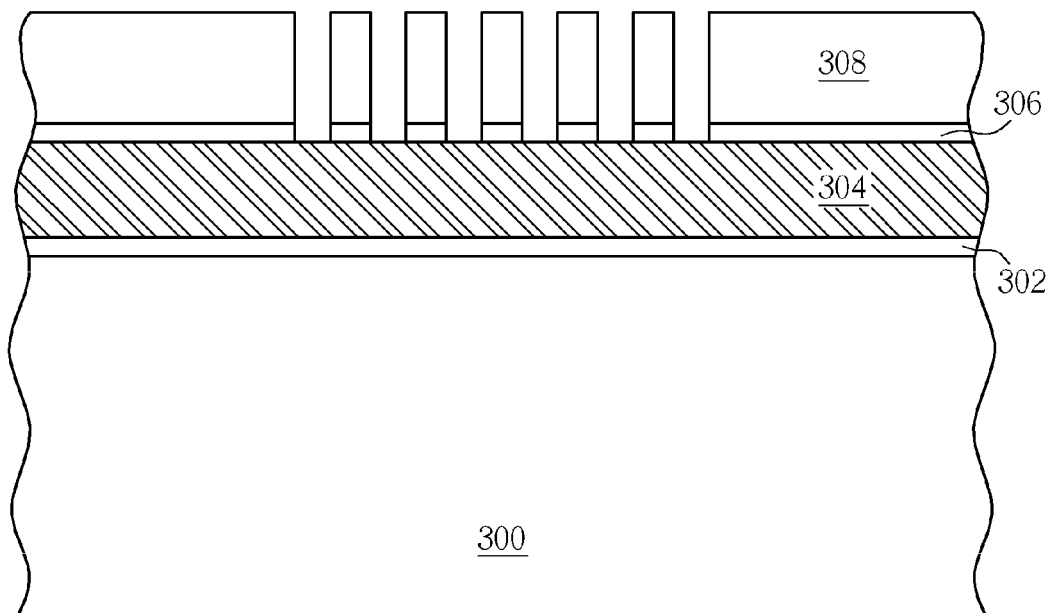


FIG. 2

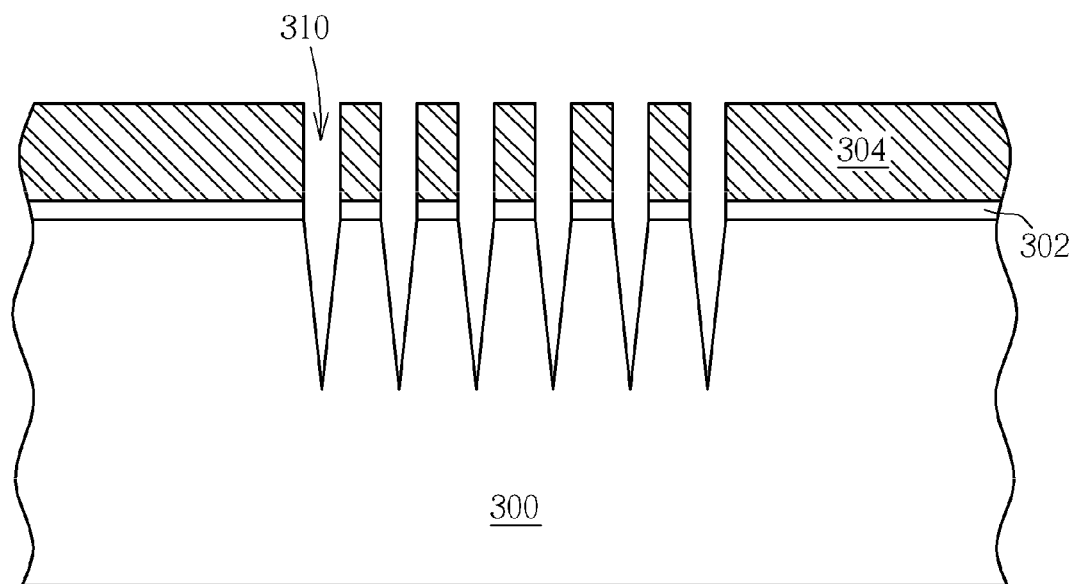


FIG. 3

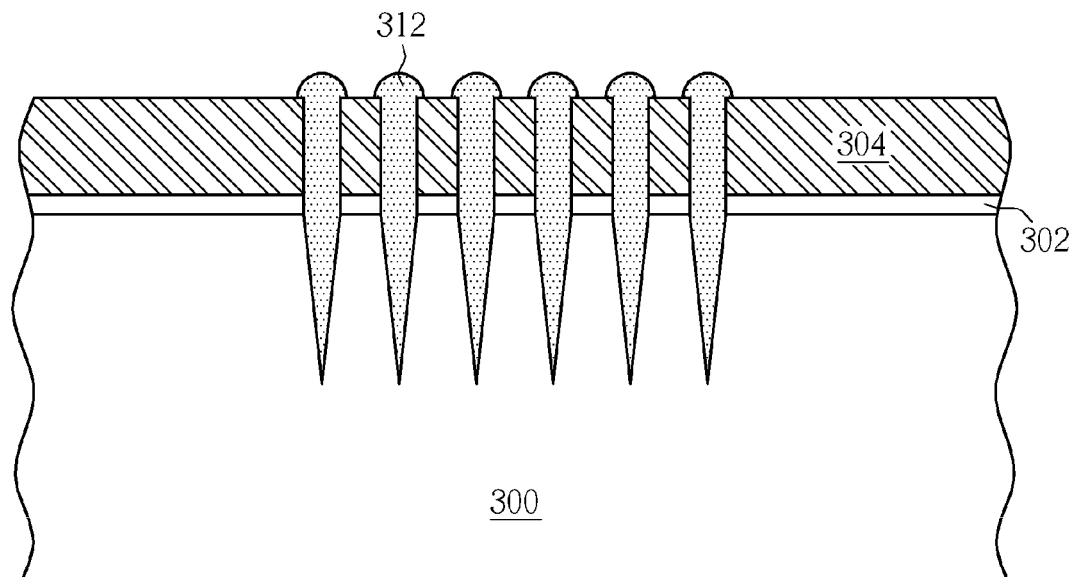


FIG. 4

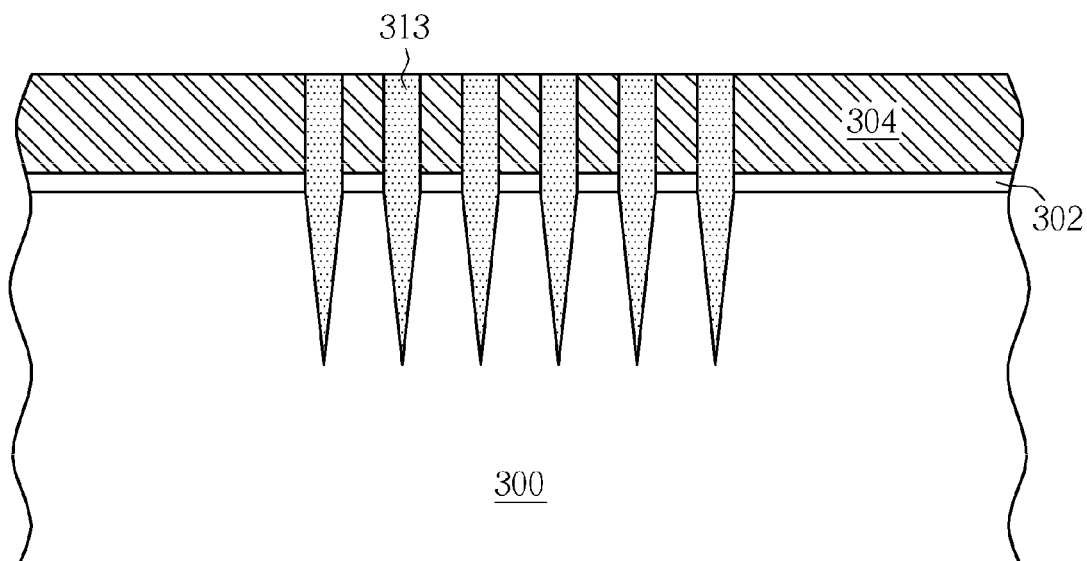


FIG. 5

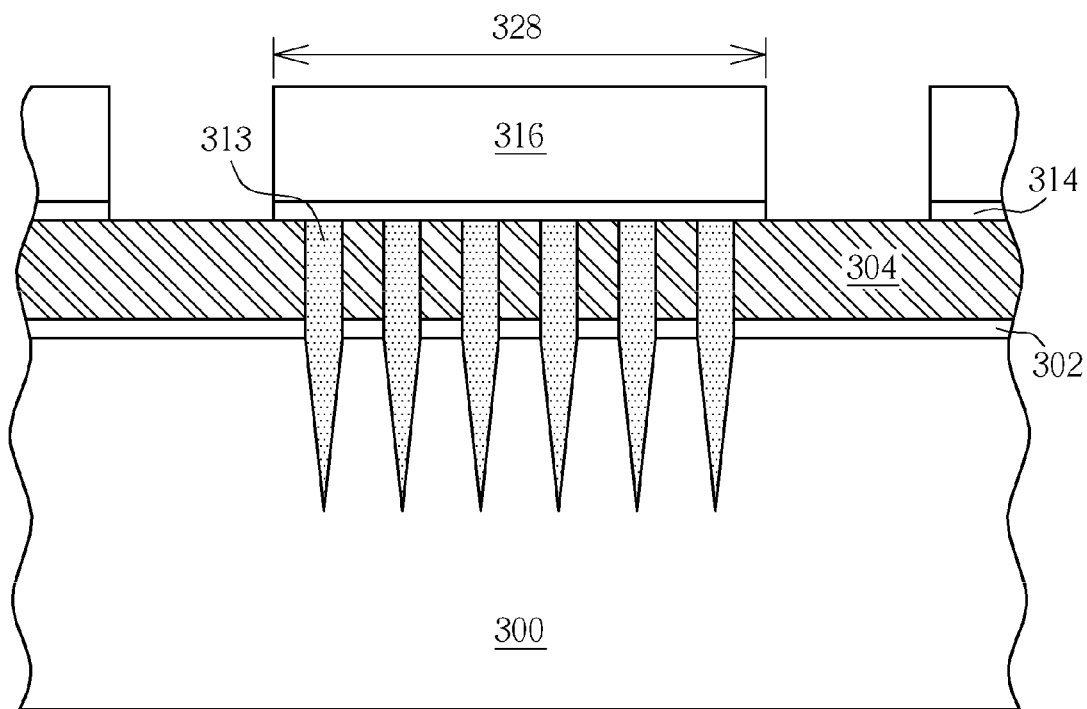


FIG. 6

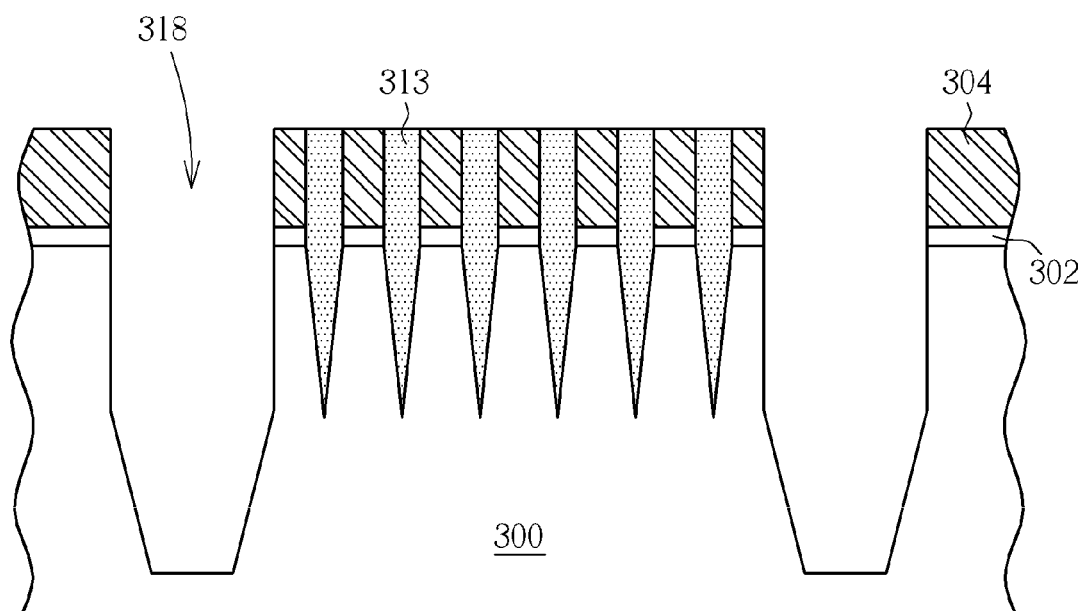


FIG. 7

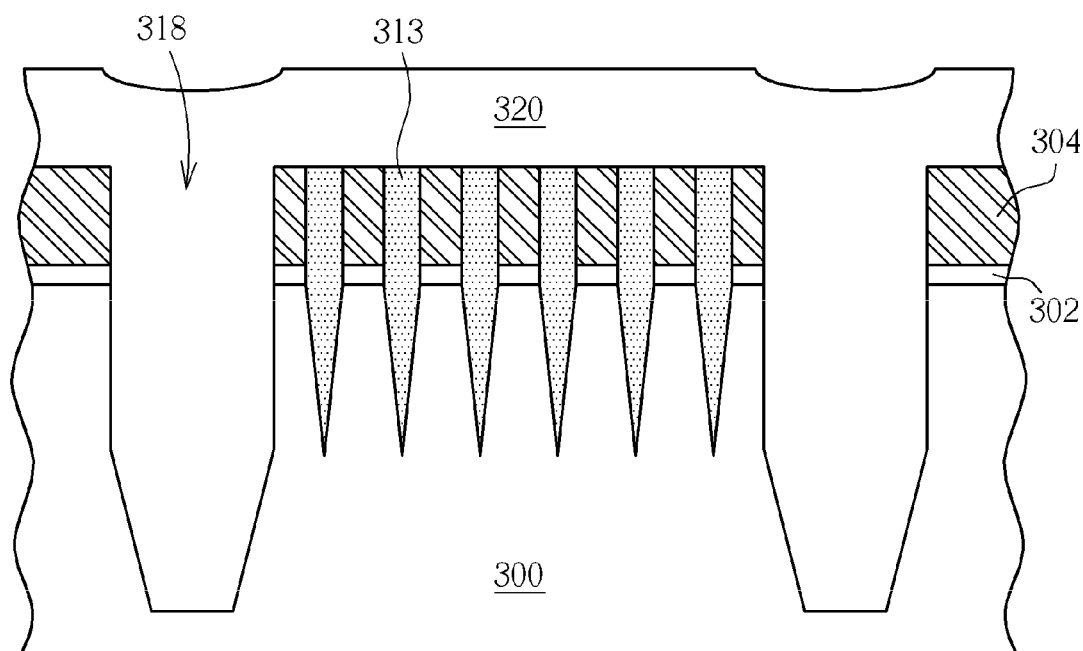


FIG. 8

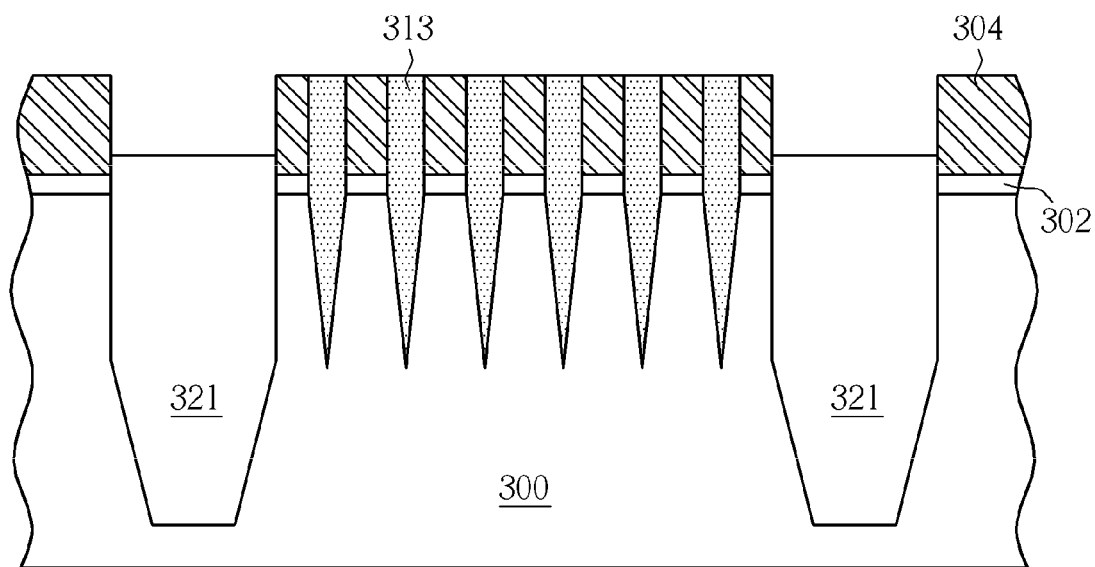


FIG. 9

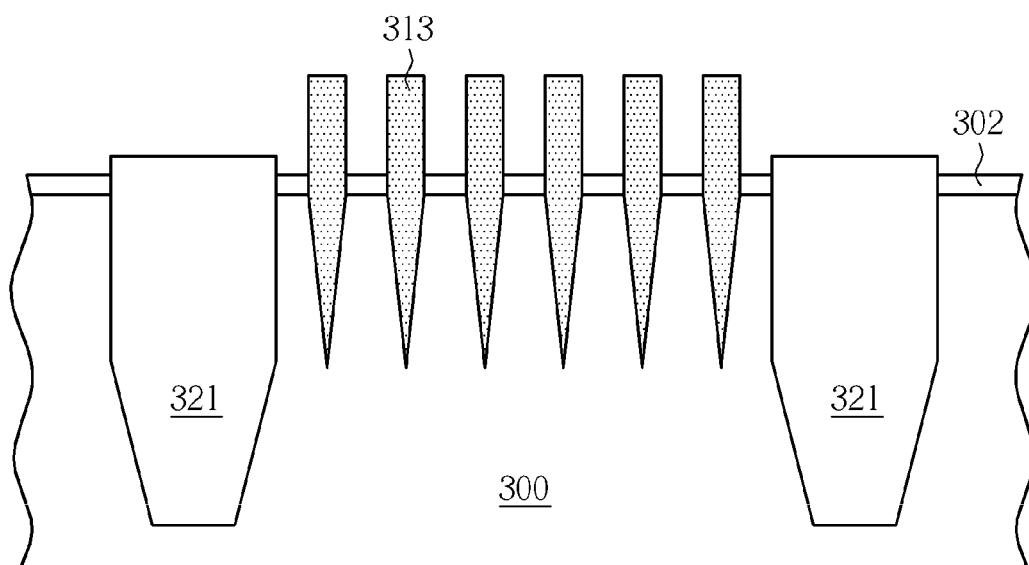


FIG. 10

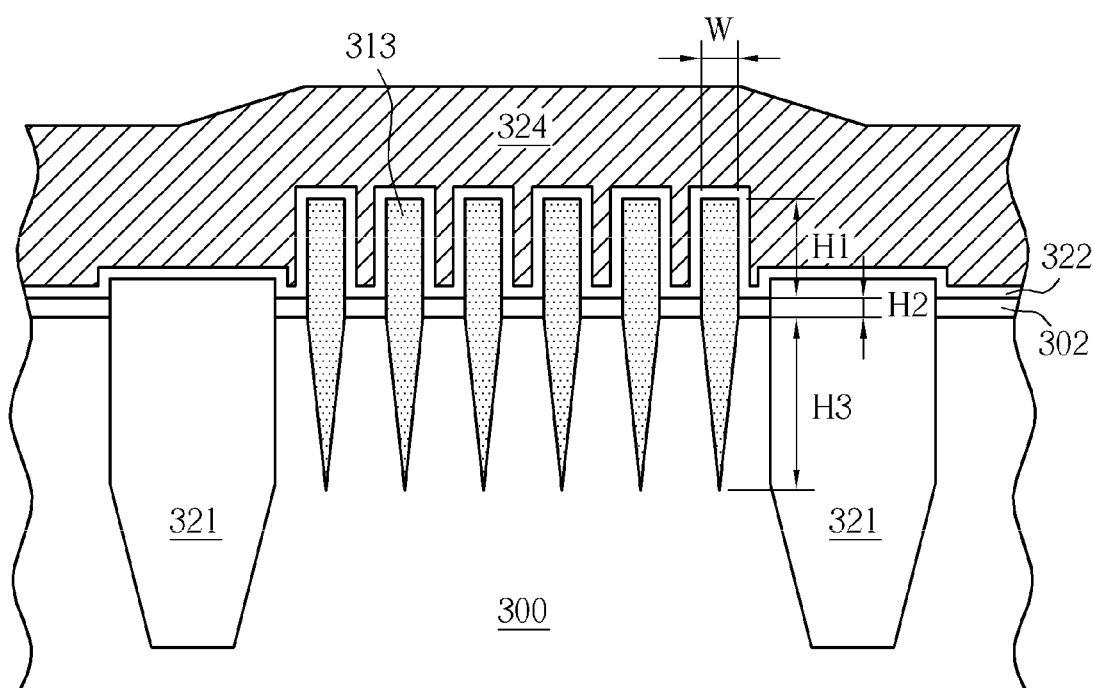


FIG. 11

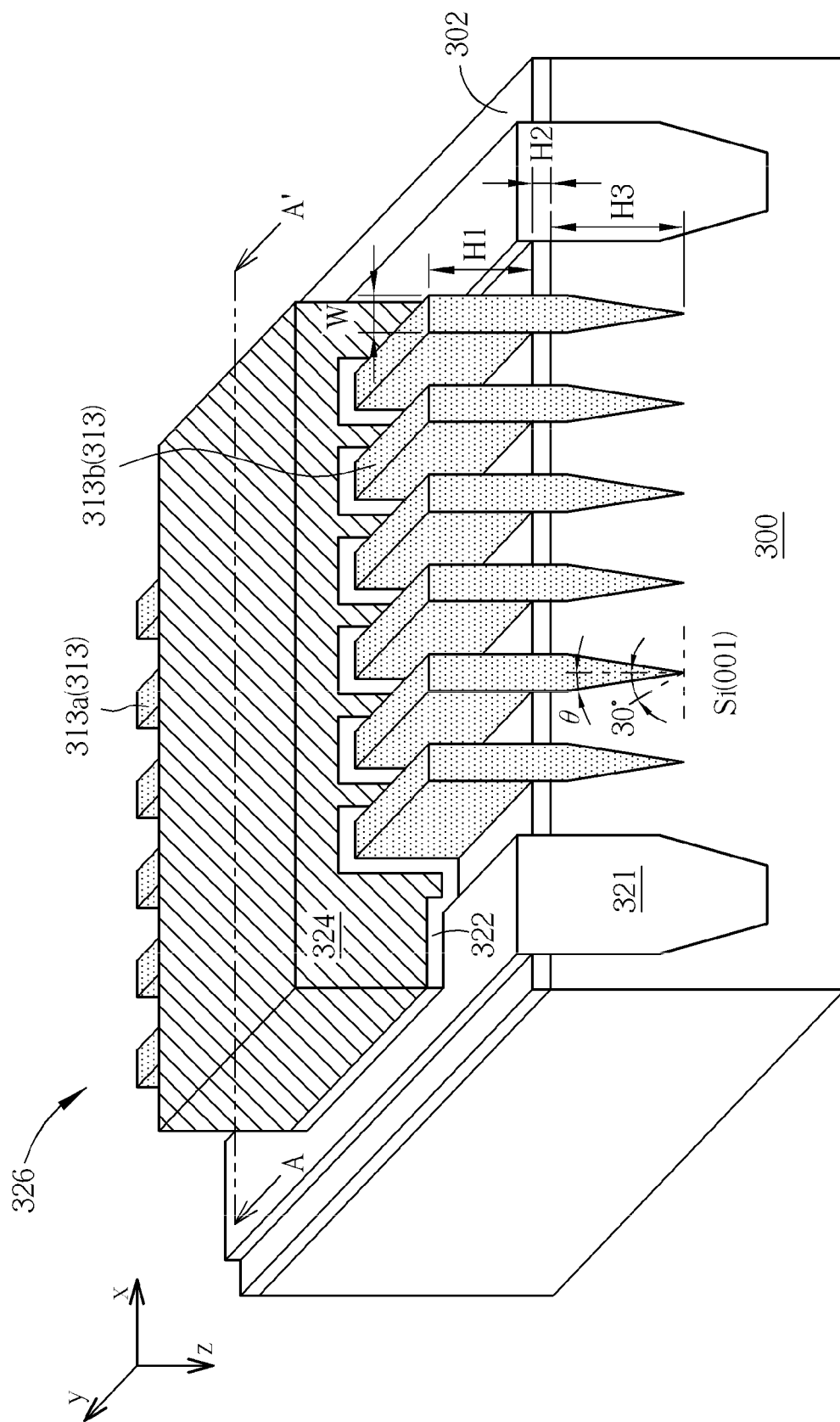


FIG. 12

FIN-FET AND METHOD OF FORMING THE SAME

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a Fin-FET and the method of forming the same, and more particularly, to a Fin-FET having an embedded fin structure and the method of making the same.

2. Description of the Prior Art

In recent years, as various kinds of consumer electronic products are being constantly modified towards miniaturization development, the size of semiconductor components are modified to be reduced accordingly, in order to meet high integration, high performance, low power consumption, and the demand of products.

However, with the miniaturization development of the electronic products, current planar transistors no longer meet the requirements of the products. Thus, there is a development for non-planar transistor such as fin field effect transistors (Fin-FET) to achieve a high drive current and to lessen short channel effect. Because the Fin-FET basically has a three-dimensional structure, the forming method thereof is more complicated than that of the traditional structure. Generally, the Fin-FET is formed on a silicon-on-insulator (SOI) substrate. There are still some problems needing to be overcome when forming the Fin-FET on traditional bulk-silicon substrate.

Therefore, there is still a need for a novel method of manufacturing a Fin-FET device.

SUMMARY OF THE INVENTION

The present invention therefore provides a Fin-FET and a method of making the same. The method can be applicable to a traditional silicon substrate and the yields of the product can be improved.

According to one embodiment, a method of forming a Fin-FET is provided in the present invention. A substrate is provided, then a mask layer is formed thereabove. A first trench is formed in the substrate and the mask layer. A semiconductor layer is formed in the first trench. Next, the mask layer is removed such that the semi-conductive layer becomes a fin structure embedded in the substrate and protruded above the substrate. Finally, a gate layer is formed on the fin structure.

According to another embodiment, a Fin-FET is provided. The Fin-FET includes a substrate, a fin structure, a gate dielectric layer and a gate layer. The fin structure is embedded in the substrate and protruding above the substrate. The gate dielectric layer disposed on a surface of the fin structure. The gate layer is disposed on the gate dielectric layer.

By using the selective epitaxial growth process to form the fin structure, in combination of the tapered sidewall and the CTA process, the quality of the fin structure can be enhanced, so the yields of the products can be improved. Moreover, in comparison with traditional Fin-FET which is mostly formed on SOI substrate, the forming method can be applicable to silicon substrate, thereby increasing the flexibility of forming methods.

These and other objectives of the present invention will no doubt become obvious to those of ordinary skill in the art after reading the following detailed description of the preferred embodiment that is illustrated in the various figures and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 to FIG. 11 illustrate schematic diagrams of the method of making the Fin-FET in the present invention

FIG. 12 illustrates a schematic diagram of the Fin-FIN in the present invention.

DETAILED DESCRIPTION

To provide a better understanding of the presented invention, preferred embodiments will be made in detail. The preferred embodiments of the present invention are illustrated in the accompanying drawings with numbered elements.

First, please refer to FIG. 12, illustrating a schematic diagram of the Fin-FIN in the present invention. As shown in FIG. 12, the Fin-FET 326 in the present invention is disposed in an active region surrounded by a shallow trench isolation 321. The Fin-FET 326 includes a substrate 300, at least a fin structure 313, a material layer 302, a gate dielectric layer 322 and a gate layer 324. The substrate 300 may be a bulk silicon substrate, a germanium substrate or an SOI substrate. The material layer 302 is disposed on the substrate 300. In one preferred embodiment of the present invention, the material layer 302 includes silicon dioxide (SiO₂).

The fin structure 313 is embedded in the substrate 300, and protrudes from the substrate 300 through the material layer 302. Each fin structure 313 extends along the y direction and is parallel to each other along the x direction. As shown in FIG. 12, each fin structure 313 has a width W, a thickness H1 protruding from the material layer 302, a thickness H2 through the material layer 302, and a thickness H3 embedded in the substrate 300. In one preferred embodiment of the present invention, the width W is substantially between 100 angstroms (Å) and 200 Å, the thickness H1 substantially greater than twice of the width W, the thickness H2, depending on the design of device, can be substantially about 0.5 the width W, or can be 0.5~2 W, or can be greater than or equal to the width W, and the thickness H3 is substantially between 100 Å and 500 Å. In addition, the fin structure 313 in the present invention includes a tapered structure shrinking toward the substrate 300. Preferably, the angle θ of the tapered structure is less than 30 degrees. The fin structure 313, for example, can be a silicon layer, a germanium layer, a silicon-germanium layer or the combination thereof. The fin structure 313 may further include a source region 313a and a drain region 313b, which are separated by the gate layer 324 and are formed by an implanting process with appropriate concentration and electrical properties of dopants.

The gate layer 324 is disposed on the gate dielectric layer 322 and extends along the x direction to cover at least one fin structure 313. The gate layer 324 can include a variety of conductive materials, such as polysilicon or metal. The gate dielectric layer 322 is disposed between the gate layer 324 and the fin structure 313 and covers a surface of the fin structure 313. Specifically, the gate dielectric layer 322 is disposed on a sidewall and/or a top surface of the portions of the fin structure 313 protruding from the substrate 300 (that is, the portion of fin structure 313 having a thickness H1). The gate dielectric layer 322 can be, for example, a silicon layer or a high-k dielectric layer. The high-k dielectric layer can be selected from a group consisting of, for example, hafnium oxide (HfO₂), hafnium silicon oxide (HfSiO₄), hafnium silicon oxynitride (HfSiON), aluminum oxide (Al₂O₃), lanthanum oxide (La₂O₃), tantalum oxide (Ta₂O₅), yttrium oxide (Y₂O₃), zirconium oxide (ZrO₂), strontium titanate oxide (SrTiO₃), zirconium silicon oxide (ZrSiO₄), hafnium zirconium oxide (HfZrO₄), strontium bismuth tantalite

($\text{SrBi}_2\text{Ta}_2\text{O}_9$, SBT), lead zirconate titanate ($\text{PbZr}_x\text{Ti}_{1-x}\text{O}_3$, PZT) and barium strontium titanate ($\text{Ba}_x\text{Sr}_{1-x}\text{TiO}_3$, BST).

It is understood that the x direction, y direction and z direction mentioned above only provide reference of relative positions. The substrate **300** may be rotated 90 degree clockwise or counterclockwise. For example, the fin structure **313** can extend along the x direction and is parallel to each other along the y direction and the gate layer **324** can extend along the y direction. The arrangement is variation and moderation of this invention and should be also within the scope of this invention.

In order to enhance the electrical performance of the Fin-FET **326**, the invention further provides various embodiments shown below. In one embodiment of the present invention, the Fin-FET **326** further includes a strained silicon layer (not shown) disposed between the fin structure **313** and the gate dielectric layer **322**. For example, the strained silicon layer can be disposed on the top surface and/or the sidewall of the fin structure **313**. In another embodiment, if the fin structure **313** includes a relaxed SiGe layer, a second SiGe layer (not shown) can be disposed between the fin structure **313** and the gate dielectric layer **322**, wherein a concentration of Ge in the second SiGe layer is greater than that in the fin structure **313**.

Please refer to FIG. 1 to FIG. 11, illustrating schematic diagrams of the method of making the Fin-FET in the present invention, wherein FIG. 1 to FIG. 11 are illustrated according to the cross-sectional view taken along line AA' in FIG. 12. As shown in FIG. 1, a substrate **300** such as a silicon substrate is provided. Then, a material layer **302** and a mask layer **304** are formed on the substrate **300** in series. In one preferred embodiment of the present invention, the material layer **302** includes SiO_2 and the mask layer **304** includes SiN.

As shown in FIG. 2, a patterned photoresist layer **308** is formed on the mask layer **304** to define the position of the fin structures **313**. In one preferred embodiment, one or more than one bottom-anti-reflection-coating (BARC) **306** can be selectively formed between the patterned photoresist layer **308** and the mask layer **304**.

As shown in FIG. 3, at least one etching process is performed by using the patterned photoresist layer **308** as a mask. During the etching process, the mask layer **304**, the material layer **302** and the substrate **300** not covered by the patterned photoresist layer **308** are removed away, thereby forming a plurality of first trenches **310**. In one preferred embodiment of the present invention, the first trenches **310** include tapered sidewalls shrinking towards the substrate **300**. The tapered angle is much less than 30 degrees. Next, the patterned photoresist layer **308** and the BARC **306** are removed away.

As shown in FIG. 4, a selective epitaxial growth process is performed by using the substrate **300** as a seed layer, thereby forming a semiconductor layer **312** in each of the first trench **310**. The semiconductor layer **312** is grown from the bottom of the first trench **310** and further grown above the top surface of the mask layer **304**. In one embodiment of the present invention, the semiconductor layer **312** includes silicon, germanium, silicon-germanium, or the combination thereof. The semiconductor layer **312** may include a single-layered structure or a multi-layered structure with appropriate stress. In general, if the substrate **300** is Si and the semiconductor layer **312** is Ge or SiGe, the dislocation usually occurs at the position about 30 degrees relative to the Si (001). For example, in FIG. 12, the Si (001) surface is parallel to the surface of the Si substrate **300** (the x direction), the tapered angle θ is thus positioned between the tapered sidewall and the z axis. Since the first trench **310** has a tapered sidewall and the tapered angle is much less than 30 degrees, when performing the

selective epitaxial growth process, the dislocation of the semiconductor layer **312** or other lattice defects would glide upwardly along the tapered sidewall of the first trench **310**. When meeting the sidewall of material layer **302** containing SiO_2 , the dislocations will be trapped thereto through an aspect ratio trapping (ART) mechanism. Therefore, the semiconductor layer **312** in the present invention can be free of dislocations and thus has better quality. It is noted that, although the position of the dislocation would change as the materials of the substrate **300** and the semiconductor layer **312** change, however, since the materials of the substrate **300** and the semiconductor layer **312** usually include diamond structure, the dislocation is still easy to occur at the position about 30 degrees relative to the Si (001). Thus, most of the dislocation defects can be prevented by using the tapered sidewalls set forth in the present invention.

In another embodiment of the present invention, after performing the selective epitaxial growth, a cyclic thermal annealing (CTA) process can be carried out. The CTA process may include a high temperature annealing step, and then a low-temperature annealing step over several cycles. In one preferred embodiment, the high temperature annealing step is held under 850 to 900 degrees Celsius, preferably 900 degrees Celsius, for 5 minutes and the low temperature annealing step is held under 350 to 450 degrees Celsius, preferably 400 degrees Celsius for 5 minutes, and a lot of cycles (for example, 3 cycles) are performed. Due to the difference of the thermal expansion coefficient between the semiconductor layer **312** and the substrate **300**, the CTA process can promote the dislocations of the semiconductor layer **312** moving toward the material layer **302**, thereby reducing the lattice defects phenomenon.

As shown in FIG. 5, a planarization step such as a chemical mechanical polishing (CMP) process is performed to remove the semiconductor layer **312** above the mask layer **304**, making the semiconductor layer **312** being level with the mask layer **304**. In this step, the semiconductor layer **312** thus becomes a plurality of fin structures **313**. Each fin structure **313** is substantially parallel to each other and is disposed in the first trench **310**. Each fin structure **313** protrudes from the substrate **300** and is level with the mask layer **304**.

As shown in FIG. 6, a patterned BARC **314** and a patterned photoresist layer **316** are formed on the mask layer **304**. An active region **328** and the position of the STI formed in the subsequent steps are therefore defined. The fin structures **313** are located in the active region **328**. Then, as shown in FIG. 7, by using the patterned photoresist layer as a mask, an etching process is performed to remove the mask layer **304**, the material layer **302**, and the substrate **300** not covered by the patterned photoresist layer **316**, thereby forming a plurality of second trenches **318** in the substrate. The depth of the second trench **318** is greater than that of the first trench **310**. In one embodiment, the depth of the second trench **318** is substantially between 2000 Å and 3000 Å. Then, the patterned photoresist layer **316** and the patterned BARC **314** are removed.

As shown in FIG. 8, an insulation layer **320** is formed on the substrate **300** to completely fill the second trench **318**. The method of forming the insulation layer **320** may include a deposition process such as PECVD. The insulation layer **320** may be a SiO_2 layer. Then, as shown in FIG. 9, a planarization process is performed to remove the insulation layer **320** above the mask layer **304**. An etching back process is carried out to remove a part of the insulation layer **320** in the second trench **318**. Thereafter, the insulation layer **320** is slightly higher than the material layer **302** and forms a plurality of shallow trench isolations **321**. It is noted that, the previous embodiment provides forming the fin structure **313** (FIG. 1 to FIG. 4)

5

and then forming the STI 321 (FIG. 5 to FIG. 8). In another embodiment, the STI 321 can be formed before forming the fin structure 313.

As shown in FIG. 10, an etching process is performed to remove the mask layer 304. In one embodiment, when the mask layer 304 is SiN, it can be removed by using hot phosphoric acid. In another embodiment, a strained silicon layer (not shown) can further be formed on the sidewall and/or the top surface of the fin structure 313. In another embodiment, when the fin structure 313 includes a relaxed SiGe layer, a second SiGe layer (not shown) can be formed on the fin structure 313, wherein a concentration of Ge in the second SiGe layer is greater than that of the fin structure 313.

Finally, as shown in FIG. 11, a gate dielectric layer 322 is formed to cover the fin structure 313. The gate dielectric layer 322 can be, for example, a silicon layer or a high-k dielectric layer. Then, a gate layer 324 can be formed on the gate dielectric layer 322. The gate layer 324 can include a variety of conductive materials, such as polysilicon or metal. Next, after patterning the gate layer 324 to form the required gate structure, an ion implantation process is carried out to form the source region 313a and the drain region 313b of the fin structure 313 as shown in FIG. 12. Through the above steps, the Fin-FET 326 structure in FIG. 12 can be provided. In another embodiment, an inter-layer dielectric (ILD) layer (not shown) can be further formed on the Fin-FET 326, and a plurality of contact holes (not shown) are formed therein to provide appropriate input/output pathway toward outer circuits.

It is appreciated that the aforementioned embodiment depicts a "gate first process." However, the present invention can also be applicable to a "gate last process." For example, the gate layer 324 can be used as a sacrifice gate which can be removed after forming the ILD layer. Thereafter, a low-resistive gate such as a metal gate can be formed to serve as a real gate. Consequently, a "gate-last process" can be carried out.

It is noted that, the width W, the thickness H1, the thickness H2 and the thickness H3 of the fin structure 313 can be adjusted by controlling the parameters in the fabrication process described above. For example, the width W and the thickness H3 can be determined by the first trench 310 in FIG. 3. The thickness H1 and the thickness H2 can be determined by the thickness of mask layer 304 and the thickness of the material layer 302 respectively. By adjusting the parameters to determine the ratio of the width W and thickness H1, different types of non-planar transistors, such as FIN-FET (if $H1 > 2W$), trigate (if H1 is about W) or segment-FET (if H1 is about 0.5 W), can be provided according to the design of products. In addition, by using the selective epitaxial growth process to form the fin structure, in combination of the tapered sidewall and the CTA process, the quality of the fin structure can be enhanced, so the yields of the products can be improved. Moreover, in comparison with traditional Fin-FET which is mostly formed on SOI substrate, the forming method can be applicable to silicon substrate, thereby increasing the flexibility of forming methods.

Those skilled in the art will readily observe that numerous modifications and alterations of the device and method may be made while retaining the teachings of the invention.

6

What is claimed is:

1. A method of forming a Fin-FET, comprising:
 - providing a substrate;
 - forming a mask layer on the substrate;
 - forming a first trench having an acute angle less than 30 degrees in the mask layer and the substrate;
 - forming a semiconductor layer in the first trench;
 - completely removing the mask layer such that the semiconductor layer becomes a fin structure embedded in the substrate and protruding from the substrate; and
 - forming a gate layer on the fin structure.
2. The method of forming a Fin-FET according to claim 1, wherein after forming the semiconductor layer further comprises forming a STI to define an active region.
3. The method of forming a Fin-FET according to claim 2, wherein the STI is formed before removing the mask layer.
4. The method of forming a Fin-FET according to claim 1, wherein the step of forming the semiconductor layer comprises a selective epitaxial growth process.
5. The method of forming a Fin-FET according to claim 1, wherein the step of forming the semiconductor layer comprises a cyclic thermal annealing process.
6. The method of forming a Fin-FET according to claim 1, further comprising forming a material layer between the substrate and the mask layer.
7. The method of forming a Fin-FET according to claim 6, wherein the material layer comprises SiO₂.
8. The method of forming a Fin-FET according to claim 1, wherein the semiconductor layer comprises a silicon layer, a germanium layer, a silicon-germanium layer or the combination thereof.
9. A method of forming a Fin-FET, comprising:
 - providing a substrate;
 - forming a mask layer on the substrate;
 - forming a first trench having a tapered angle less than 30 degrees in the mask layer and the substrate;
 - forming a semiconductor layer in the first trench;
 - forming a STI to define an active region, wherein the semiconductor layer is disposed in the active region;
 - after forming the STI, completely removing the mask layer such that the semiconductor layer becomes a fin structure embedded in the substrate and protruding from the substrate; and
 - forming a gate layer on the fin structure.
10. The method of forming a Fin-FET according to claim 9, wherein the step of forming the semiconductor layer comprises a selective epitaxial growth process.
11. The method of forming a Fin-FET according to claim 9, wherein the step of forming the semiconductor layer comprises a cyclic thermal annealing process.
12. The method of forming a Fin-FET according to claim 9, further comprising forming a material layer between the substrate and the mask layer.
13. The method of forming a Fin-FET according to claim 12, wherein the material layer comprises SiO₂.
14. The method of forming a Fin-FET according to claim 9, wherein the semiconductor layer comprises a silicon layer, a germanium layer, a silicon-germanium layer or the combination thereof.

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